11th EUROPEAN UNION SCIENCE OLYMPIAD

Test 2

Marking scheme

Luxembourg, March 21th, 2013

TASK 1: Microbiology of biogas production(20 marks)

1.1. Gram coloration of the samples (2 marks)

⇨ mark the right answer with an (X)

Sample (A)

Gram +	
Gram+ and Gram -	X
Gram -	

Sample (B)

Gram +	
Gram+ and Gram -	
Gram -	X

1.2 Quality of the microscopic preparation of sample A (5 marks)

Excellent	5 marks
Good	3 marks
Medium	2 marks
Poor	1 mark

1.3 Microbes not involved in Methane production in the biogas plant of Alfred BIOMAN (sample A) (2 marks)

⇨ mark the microbes that are not involved in Methane production with an (X)

Archaea	- 1
Bacteria	- 1
Protista	0.5
Plantae	0.5
Fungi	0.5

1.4 **Microbes present in sample (B):** (1 mark)

⇨ use the numbers from the identification sheet

5

1.5 **Drawing of the sample (A) (field of view of microscope x 1000) and identificatiopn of microorganisms present.** (5 marks)

Make a drawing of the microorganisms present in sample (A) and name the specimens using the numbers from the identification sheet.

1 mark: general quality of drawing 1 mark: relative dimensions of microorganisms 3 marks : drawing and correct annotation

1.6 **Concerning the cell wall structure of Archaea you can say after observation of sample (B) that these microorganisms:** (1 mark)

Have a Peptidoglycan cell wall	
Don't have a Peptidoglycan cell wall	1

1.7 **Gram staining:** (1 mark)

Is suitable to distinguish Archaea from Bacteria	
Is not suitable to distinguish Archaea from Bacteria	1

1.8 **Duplication ratio:** (3 marks)

How much time need the most common species of microorganisms from the metioned groups for duplicating there cells once?

Duplication time	0.5-1 hour	1-5 hours	1-2 days	10-15 days
Archaea			0.5	0.5
Bacteria	1			
Yeast (Eukaryota, Fungi)		1		

TASK 2: Identifications of two gases in a biogas mixture (18 marks)

Experimental procedure (2 marks)

2.1 m_1 = 2.2 m_2 = 2.3 m_3 = 2.4 n_x/n_y = 1

2 marks (within 20 % error)

Calculations (10 marks)

2.5. Calculation of m_A

$m_A = m_1 -$ (mass of 50 mL air)

$= m_1 - 0.0602$ g (2 marks)

2.6 Calculation of m_B

$m_B = m_2 - m_A$

2.7.1 Calculation of m_X

$m_X = m_3 - m_A$

2.7.2 Calculation of M_x

$n_x = pV/RT$

$M_x = m_x/n_x$ (4 marks)

2.7.3 Calculation of M_y

$m(25 \text{ mL } Y) = m_B - (m_x/2)$

$M_Y = m(25 \text{ mL } Y)/(n_x/2)$ (4 marks)

error	$M(CH_4)$	$M(CO_2)$	**points**
<10%	14.4-17.6	39.6-48.4	4
10-20%	12.8-19.2	35.2-52.8	2
20-30%	11.2-20.8	30.8-57.2	1
>30%	<11.2 />20.8	<30.8/>57.2	0

Conclusions

Formula of gas X = CH_4 Formula of gas Y = CO_2

Additional questions (5 marks)

2A Indicate for each of the following statements if they are true or false (2 marks)

In the ideal gas law:	True	False
A. the volume of the molecules is negligible.	X	
B. the gas itself does not exert any pressure.		X
C. the atomic radius is larger than 10 nm.		X
D. there are no intermolecular interactions.	X	
E. the gas is not soluble in water.		X

For each wrong answer 1 point is deduced

2B Indicate for each of the following statements if they are true or false (3 marks)

Methane:	True	False
A. gives rise to a stronger greenhouse effect than carbon dioxide.	X	
B. can combine with water at the bottom of the oceans.	X	
C. is very soluble in water.		X
D. forms a cubic molecular structure.		X
E. has a typical smell of a combustible gas.		X

For each wrong answer 1 point is deduced

TASK 3: Monitoring the biogas production process (16 marks)

3.1.1 What is the average volume of gas produced in the eudiometer after adding the acid ? (5 marks)

Assay 1		mL/100 mL digestate
Assay 2		mL/100 mL digestate

Deviation from the actual measurement	Attributed marks
<10%	5
10%< x < 20%	2
> 20%	0

Assay 3		mL/100 mL digestate
Average		**mL/100 mL digestate**

3.1.2 What is the major gas produced in the reaction bottle? (1 mark)

- Methane (CH_4) and carbon dioxide (CO_2) ☐
- A mixture of 50% CO_2 and 50% CH_4 and traces of H_2S ☐
- Pure carbon dioxide (CO_2) ☐
- A mixture of mainly CO_2 and traces of H_2S ☒

X	-0.5
X	-0.5
X	-0.5
X	+1

- Pure hydrogen sulphur (H_2S) ☐
- A mixture of mainly CH_4 and traces of Hydrogen (H_2) ☐

3.1.3 What happened to the buffer capacity of the digestate after the reaction in the eudiometer? (1 mark)

- The buffer capacity is reinforced by the addition of the diluted strong acid (HCl). ☐
- The buffer capacity of the digestate is completely exhausted by the strong acid. ☒
- The buffer capacity remains identical to that of the original digestate. ☐
- The buffer capacity is decreased by the addition of the diluted strong acid (HCl). ☐
- The buffer capacity is stable in all scenarios ☐

X	-0.5
X	+1
X	-0.5
X	-0.5
X	-0.5

3.1.4 What are the weak acids formed in water when CO_2 and H_2S are solubilized in the digestate in the absence of oxygen? (1 mark)

- Sulfuric acid (H_2SO_4) and Hydrochloric acid (HCl): ☐
- Hydrosulfuric acid (H_2S) and Hydrochloric acid (HCl): ☐
- Carbonic acid (H_2CO_3) and Sulphuric acid (H_2SO_4): ☐
- Hydrosulfuric acid (H_2S) and Carbonic acid (H_2CO_3): ☒
- Carbonic acid (H_2CO_3) and Sulphuric acid (H_2SO_4): ☐
- Carbonic acid (H_2CO_3) and Hydrochloric acid (HCl): ☐

X	-0.5
X	-0.5
X	-0.5
X	+1
X	-0.5
X	-0.5

3.1.5 Based on the measurement made with the eudiometer, calculate the buffer capacity (syn. total alkalinity) of the digestate in terms of $CaCO_3$ equivalent? (2 marks)

1 mole of CO_2 (1 mole = 22.4 L) is liberated from 1 mole of $CaCO_3$ (M weight = 100 g)

1 L of CO_2 is liberated from 100 g/22.4 of $CaCO_3$

1 mL of CO_2 is liberated from 100 mg/22.4 of $CaCO_3$

X mL of CO_2 is liberated from *X* x 100 mg/22.4 of $CaCO_3$

$CaCO_{3\,eq}$… *X* x 100 /22.4….mg/100 mL of digestate

Deviation from the actual measurement	Attributed marks
<10%	2
10%< x < 20%	1
> 20%	0

3.1.6 What are the approximate proportions of CH_4 and CO_2 produced by the degradation of sugars and lipids during biomethanation? (2 marks)

Calculated from the information provided in introduction:

Carbohydrates: $C_6H_{12}O_6 \rightarrow 3CO_2 + 3\ CH_4 \rightarrow 3/(3+3)*100=50\%\ CO_2$ and $3/(3+3)*100=50\%\ CH_4$

Lipids: $C_{12}H_{24}O_2 + 5\ H_2O \rightarrow 3.5\ CO_2 + 8.5\ CH_4$

$\rightarrow 3.5/(3.5+8.5)*100=29\%\ CO_2$ and $8.5/(3.5+8.5)*100=71\%\ CH_4$

Sugars → biogas with: CH_4 (%) =…**50%**….. and CO_2 (%) =…**50%**.....

Lipids → biogas with: CH_4 (%) =… **71%**…. and CO_2 (%) =…**29%**......

3.1.7 Making abstraction of the trace gas, and considering that the digester was fed exclusively with (A) glucose ($C_6H_{12}O_6$) or exclusively with (B) lipids what would be the equivalent of methane produced and corresponding to the measured volume of gas in the eudiometer? (1 mark)

A) Exclusive substrate = Glucose: mL CH_4= mL CO_2 given in A-1
B) Exclusive substrate = Lipid: CH_4 = 29% CO_2 + 71% CH_4

→ mL CH_4= mL CO_2 x 71/29, where CO_2 is the mL given in A-1

Rq: Even if the CO_2 volume given in 3.1.1 is out of range, an accurate calculation in 3.1.7 will be considered as correct.

3.1.8 If Mr Alfred Bioman wanted to know the amount of ammonia (NH_3) in solution in the biogas digestate, what would be the adequate reactant to choose while using the same eudiometer design? (1 mark)

• NaOH mixed with ammonium nitrate (NH_4NO_3) to produce an insoluble gas	☐	X	-0.5
• H_2SO_4 mixed with a strong reducing agent to transform NH_3 in an insoluble gas	☐	X	-0.5
• NaOH mixed with a strong oxidant agent to transform NH_3 in an insoluble gas	☒	X	+1
• H_2SO_4 mixed with a strong oxidant agent to transform NH_3 in an insoluble gas	☐	X	-0.5
• NaOH mixed with a strong reducing agent to transform NH_3 in an insoluble gas	☐	X	-0.5
• Water mixed with a strong oxidant agent to transform NH_3 in an insoluble gas	☐	X	-0.5

3.2.1 What are the pH values observed for the two digestates (2 marks)

For each pH value 1 mark is given according to the precision

Deviation from the actual measurement	Attributed marks
<10%	1
10%< x < 20%	0.5
> 20%	0

3.2.2 On the basis of the expertise you acquired during Tasks 3.1 and 3.2, what is your diagnosis concerning the status of Alfred Bioman's digester ? (1 mark)

• The digester pH is close to neutrality and the buffer capacity is almost equal to zero → the digester is stable	☐	X	-0.5
• The digester pH is close to neutrality and the buffer capacity is acceptable → the digester is stable	☒	X	+1
• The digester pH is acidic and the buffer capacity is acceptable → the digester is stable	☐	X	0.5
• The digester pH is acidic and the buffer capacity is almost equal to zero			

→ the digester is at risk ☐

- The digester pH is strongly alkaline and the buffer capacity is almost equal to zero

  → the digester is stable ☐

- The digester pH is strongly alkaline and the buffer capacity is high

  → the digester is at risk ☐

TASK 4: Determination of the specific heat capacity of a heat carrier liquid used in a solar collector (30 marks)

Task 4.1: Mass of calorimeter (1 mark)

Mass of the empty calorimeter (number 30) with lid and stirrer	0,390 kg

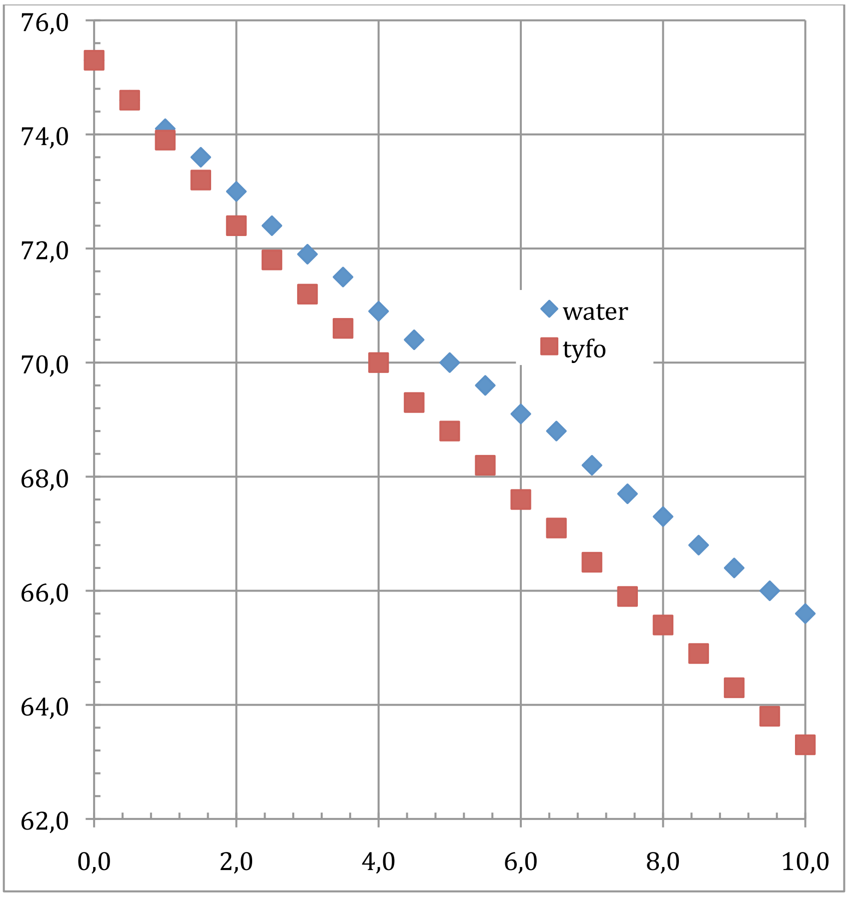
1 mark for the correct value; variations are possible for other calorimeters

Task 4.2: Table (4 marks)

Correct values: 2 marks for every liquid

Measurements from a practical test with calorimeter number 30; variations are possible

t (min)	θ_{water} (°C)	θ_{Tyfo} (°C)
0.0	75.3	75.3
0.5	74.6	74.6
1.0	74.1	73.9
1.5	73.6	73.2
2.0	73.0	72.4
2.5	72.4	71.8
3.0	71.9	71.2
3.5	71.5	70.6
4.0	70.9	70.0
4.5	70.4	69.3
5.0	70.0	68.8
5.5	69.6	68.2
6.0	69.1	67.6
6.5	68.8	67.1
7.0	68.2	66.5
7.5	67.7	65.9
8.0	67.3	65.4
8.5	66.8	64.9
9.0	66.4	64.3
9.5	66.0	63.8
10.0	65.6	63.3



Task 4.3: Cooling curves on a sheet of millimetre paper with tangents at 70°C (11 marks)

Correct size (3/4 of page) and correct scales: 1 mark
Correctly plotted values: 2 marks
Different symbols used for the different curves: 1 mark
Correctly drawn best-fit lines (between marks): 2 marks
Units on the axis: 1 mark (0.5 mark for every correct unit)
Tangents at 70°C correctly drawn: 4 marks (2 marks for each tangent)

Task 4.4: Slopes of the tangents (4 marks)

Slope of the tangent to the cooling curve of water at 70°C: $\left(\frac{\Delta\theta}{\Delta t}\right)_{water}$	-0.92 °C/min
Slope of the tangent to the cooling curve of Tyfo at 70°C: $\left(\frac{\Delta\theta}{\Delta t}\right)_{Tyfo}$	-1.25°C/min

2 marks for each correct value

Task 4.5: Specific heat capacity of Tyfo (4 marks)

Specific heat capacity of Tyfo (at 70°C)	2953 $J\cdot°C^{-1}\cdot kg^{-1}$
Specific heat capacity of Tyfo (at +30°C)	2723 $J\cdot°C^{-1}\cdot kg^{-1}$
Specific heat capacity of Tyfo (at –20°C)	2436 $J\cdot°C^{-1}\cdot kg^{-1}$

2 marks for the correct value at 70°C; uncertainties of ± 5% are possible

1 mark for each other correct value

Task 4.6: Concentration of the heat carrier mixture (1 mark)

Tyfo concentration of the heat carrier mixture in a solar collector properly working down to a temperature of –20°C	37 - 40

1 mark for the correct value

Question 4A: Specific heat capacity of a mixture (2 marks)

Specific heat capacity of the heat carrier containing 40% of Tyfocor®L at a temperature of 30°C	3597 $J\cdot°C^{-1}\cdot kg^{-1}$

2 marks for the correct value

Question 4B: Calorimeter's thermal equilibrium (3 marks)

Items	Yes	No
The material the calorimeter is made of is an excellent heat conductor	x	
The liquid inside the calorimeter is worse a heat conductor as copper		x
The plastic box favours the heat exchange		x
Cold rapidly propagates from the calorimeter to the liquid		x
Stirring the liquid	x	

For each wrong answer 1 mark is deduced

Task 5: General questions about Biomethanation (6 marks)

5A Methane synthesis

Write down the equation of methane production by acetototrophic methane producers using acetic acid (CH_3COOH):

_______$CH_3COOH \rightarrow CH_4 + CO_2$________________________________0.5 mark________

Write down the equation of methane production by hydrogenotrophic methane producers using hydrogen and carbon dioxyde:

_______$CO_2 + 3\ H_2 \rightarrow CH_4 + H_2O$________________________________0.5 mark____________

5B Calculate the total amount of petrol which could be displaced annually by the use of biomethanation for energy production in Luxembourg. (1 mark)

From the information provided in the introduction 1 m^3 biogas = 0.6 L of petrol and 34 millions of cubic meters of biogas are produced annually in Luxembourg.

Petrol displaced by biogas: 34 10^6 m^3 of biogas x 0.6 = 20.4 10^6 L of petrol______________t

5C The government of Luxembourg, in an effort to lower the greenhouse gas emissions and to meet her emissions reduction target as set by the Kyoto Protocol, may propose a levy on the ruminant farmers (flatulence tax: 0.05 € /L of CH_4 and CO_2 emitted annually) because their livestock was the biggest emitters of methane (196470 cows in total). How much money could the government of Luxembourg earn per year (365 days) by raising such a tax?

1 cow → 350 L/day CH_4 + 1500 L/day CO_2
196 470 cows → 196 470 x 350 L/day CH_4 + 196 470 x 1500 L/day CO_2
Taxes (€/day) →0.01 x 196 470 x 350 + 0.005 x 196 470 x 1500
Taxes (€/year) →365 x (0.01 x 196 470 x 350 + 0.005 x 196 470 x 1500)
→365 x (687 645 + 1 473 525) = 788 827 050 €

Annual Government earning:___ **788 827 050**____€ (2 marks)

5D Since Mr Alfred Bioman has turned his farm into a biogas unit he makes good use of the digestate as an organic fertilizer. His farm has an arable land area of 100 ha and he uses the equivalent of 170 kg of nitrogen/ha per annum (the digestate on Mr Bioman's farm contains on average 4 kg of nitrogen/m^3). Calculate how many m^3 of natural gas is saved annually thanks to the action of Mr Bioman.

100 ha x 170 kg/ha = 17 000 kg of nitrogen/year

1000 m^3 of natural gas are required for the synthesis of 1 t of reactive nitrogen

→ 17 000 m^3 of natural gas are saved annually

Natural gas saved annually: 17 000 m^3 (2 marks)